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International Conference on Information Systems (ICIS)

December 2003

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Rueylin Hsiao
National University of Singapore

Stephen Tsai
National Sun Yat-sen University

Ching-Fang Lee
National Sun Yat-sen University

THE PROBLEM OF EMBEDDEDNESS: KNOWLEDGE TRANSFER, SITUATED PRACTICE, AND THE ROLE OF INFORMATION SYSTEMS

Ruey-lin Hsiao
National University of Singapore
Singapore
bizhr@nus.edu.sg

Stephen Tsai
National Sun Yat-sen University
Taiwan, R.O.C.
dhtsai@bm.nsysu.edu.tw

Ching-Fang Lee
National Sun Yat-sen University
Taiwan, R.O.C.
cflee@cc.kyit.edu.tw

Abstract

This study examines the problems associated with the use of knowledge management systems designed for transferring internal best practices. The field research explores the nature of engineers' tacit knowledge in a dynamic context maintaining semiconductor fabrication machines. It illustrates the problem underlying the codification of tacit knowledge embedded in situated practice. Three problems of such embeddedness are explained with reference to task complexity, the collaboration mode, and industrial context. The study analyzes knowledge in actual practice in a high-velocity industry via a situated practice perspective, and suggests how it might affect the use of information systems.

Keywords: Knowledge transfer, situated practice, embeddedness, tacit knowledge, best practice, semi-conductor fabrication machine

Introduction

Intra-firm knowledge transfer is crucial for the development of information systems, but in practice, it can be difficult to accomplish. Why is this? Previous studies have examined issues regarding transfer barriers, technological features, and socio-political analysis. Although these studies have enhanced our understanding of technology and organization, we still know relatively little about the nature and scope of the practices in which these knowledge workers engaged. Without sufficient understanding of work and practice, we may not be able to manage knowledge and use information systems with confidence.

This study seeks to explore the challenges of information system enabled knowledge transfer by asking: what do knowledge workers (such as technicians and engineers) do and what do they know? By exploring engineers' practice within their actual working situations, we attempt to explain the possible constraints underlying knowledge transfer and technology use. To put this inquiry into context, we investigate the experience of engineers maintaining microchip fabrication machines. Based on interactive findings between the field research and theories, we highlight three sets of problems to understand the challenges of knowledge transfer: (1) the *complexity* of knowing: problems associated with the knowledge embedded in practices characterized by complex machine interactions; (2) the *collaboration* in knowing: problems associated with the knowledge embedded in practices characterized by reciprocal human coordination; and (3) the *context* of knowing: problems associated with the knowledge embedded in practices that are situated within a dynamic context.

The second part begins with a review of knowledge transfer, the concepts of knowledge embeddedness, and situated practice. The third part explains how we use Klein and Myers' (1999) interpretative principles to conduct the fieldwork. The fourth section reports the empirical findings by summarizing the problem of knowledge transfer. The fifth section discusses the issue of *embeddedness* within the cumulative tradition of the situated practice literature, and elaborates its implications with particular references to information systems. The last section draws our conclusions.

Knowledge Transfer, Situated Practice, and Information Systems

Sociologist Mark Granovetter (1985) uses embeddedness to explain how economic activities are embedded in and shaped by social relationships. The concept has been widely used in the current literature to explain how tacit knowledge is embedded in its situated practice. This is in stark contrast to the transfer of explicit best practices, as in the case of Texas Instruments. Texas Instruments generated $1.5 billion in annual increased production capacity by transferring best practices among its 13 existing fabrication plants. In such a case, information systems are used to store (through a database) and disseminate these best practices (through an electronic forum and the Internet) (see more examples in Dixon 2000).

There are challenges of knowledge transfer arising from barriers between the source and the recipient. According to Rivikin (2001, p. 277) and Szulanski (1996), typical barriers include ignorance (of where to identify knowledge), lack of motivation, lack of absorptive and retention capacity (on the recipient side), unfavorable access to knowledge (on the source side), obstacles to the effective search for knowledge, and unproven knowledge content. Other studies also examine problems of knowledge transfer with regard to technological features, community building (e.g., McDermott 1999), knowledge conversion (e.g., Alavi and Leinder 2001; Nonaka 1994), and socio-political issues (e.g., Hayes and Walsham 2001).

However, learning theorists suggest that these studies seem to isolate knowledge from practice (e.g., Brown and Duguid 1991; Orlikowski 2002). In their view, we should first examine how knowledge is embedded in the actual practice of experts before we can confidently assess how it may affect knowledge transfer and the use of technology. For instance, Lave and Wenger (1991) offer the idea of "legitimate peripheral participation" and suggest that transferring tacit knowledge requires adaptive learning through participation in practical situations and enculturation within the professional communities. Barley (1996) is more concerned with technicians' contextual knowledge in terms of semiotic knowledge, sensor-motor skills, heuristics, particular working styles, local idiosyncrasies, and communities-of-practice. Lam (1997) adds that tacit knowledge is embedded in engineers' practical experience and their diffusive, overlapping collaborative activities,and that knowledge is transmitted through human networks rather than documentation. Tyre and von Hippel (1997) stress that knowledge is embedded in the physical context in which engineers find themselves. Thus, engineers can only learn problem-solving clues, data gathering skills, and the use of local tools in the situated context. Cook and Brown (1999, p. 387) suggest that a more appropriate term to describe the interaction of knowledge and practice is *knowing*. Knowing means that knowledge cannot be taken away from practice and transferred from one place to another, because knowledge is embedded not only in practice but also in the dynamic interactions between people and their social context. By the same token, Orlikowski (2002, p. 253) explains five repertoires of knowing and contends that the idea of the best practice transfer is questionable. Knowledge transfer may better be seen as a developmental process of people's competency to enact *useful* practice for a specific context. Thus, we can only use technology to facilitate situated practice and cannot disembody knowledge from that practice.

In information systems research, Schultze and Boland (2000) and Nidumolu et al. (2001) explain that we are prone to misinterpret the problem of technology use if we fail to understand the situated nature of practice. For example, Schultze and Boland examine the failed implementation of KnowMor, which was designed to disseminate market intelligence (e.g., from Dow Jones) in a manufacturer of building materials. They explain how the failure was caused by the incongruence between the competitive intelligent analysts' situated practice (where they assumed the role of "information czar," controlling information access) and the practice embedded in KnowMor (which promoted a democratic model of information access). The present study seeks to add to this strand of research and emphasizes the challenges of knowledge transfer within the context of microchip fabrication equipment maintenance.

Interpretative Methods

We use Klein and Meyers' (1999, p. 72) principles to reflect how we conducted our fieldwork in accordance with the interpretative tradition. Note that these seven principles are not used mechanistically to report our research design. Rather, we use these principles to improve our research designs and the quality of the fieldwork.

The principle of the hermeneutic tradition: This research is concerned with engineers' experience in their everyday practice. We analyze the repairing tasks and the challenges surrounding engineers' sharing of their know-how via technology. We examine not only how engineers accomplish machine maintenance (the *part*) but also how their practice is situated in the integrated fabrication process, human collaboration, and the industrial context of the semiconductors industry (the *whole*).

The principle of contextualization: We examine the system with reference to the socio-historical background of the company. During the fieldwork, we asked engineers to describe how they dealt with machine breakdowns and what the discovery process of problem resolution involved, rather than asking them merely to recall their step-by-step troubleshooting procedures. We aim to illustrate the contextual dynamics of problem-solving in order to explain the actual practice of these engineers.

The principle of interaction between the researchers and the subjects: The research site is based in the Hsin-chu Science Park (in northern Taiwan) and the Tainan Science Park (in southern Taiwan). We conducted a pilot study during the period from March to April 2002, interviewing 31 engineers. Each interview lasted an average of two hours. The first and third researchers conducted personal interviews and field observation (in different fabrication plants); the second researcher negotiated other site visits.

Initially, we attempted to examine how knowledge was codified by and disseminated through the system. Interactions with the engineers led us to question many of our presumptions. As we came to appreciate the nature and scope of the engineers' work, we identified a more suitable theoretical orientation: the situated practice perspective (Lave and Wenger 1991). During May-November 2002, the third researcher maintained regular visits (once a week on average) to various client sites. Later, between January and March 2003, we conducted follow-up interviews with 12 selected engineers in order to achieve a better understanding of how knowledge was enacted from onsite maintenance. This time, we asked the engineers to provide their "war stories" of repair activities (Orr 1996). In a typical interview, we followed three guiding questions. (1) How long have you worked on this job? (This was intended to identify whether the engineer was a newcomer or an old-timer.) (2) Could you name the most impressive repair "battle" in your career? (This was an attempt to elicit war stories.) (3) Could you give us the details of this repair event? We asked for information concerning the content of repairing tasks, the discovery process of trouble-shooting, and the context in which the repairing work was accomplished.

The principle of abstraction and generalization: Our interpretation is anchored in the theory of situated practice. Base on this viewpoint, we coded data inductively according to the practice situated in three related contexts: (1) the *technical* context: analyzing how individual machines were related to the fabrication process; (2) the *social* context: examining how the engineers collaborated with each other; (3) the *industrial* context: investigating how fast technological innovations affected the lifecycle of knowledge content (principle of contextualization). On these bases, we examined the engineers' assessment of the knowledge transfer systems.

The principle of dialogical reasoning: The theory of situated practice oriented us through two cycles of revision. First, we examined the characteristics of engineers' tacit knowledge. Our purpose was to identify the incongruence between the knowledge embedded in practice and the knowledge embedded in technology. Nevertheless, the engineers' assessments of the system were too generic (e.g., "it's not a troubleshooting situation; it's a sense of discovery"). In most repair situations, the engineers counted less on sensor-motor skill and heuristics, and more on dynamic interaction with machines and people. For them, each repair situation was unique and dynamic: "we don't have heuristics," one engineer repeatedly emphasized. In the second revision, we began to investigate what these engineers meant by "too complex," "sense of discovery," and "unique and dynamic context." We found useful references in the concepts of interactive complexity (Perrow 1999), reciprocal interdependency (Kumar and van Dissel 1996), and disruptive innovation (Christensen 1997). These concepts helped us to analyze data according to the practice lens under three headings: (1) practice that was integrated in the complex interaction and tight coupling of the fabrication process; (2) practice that was enacted from reciprocal collaboration among engineers; and (3) practice that was situated in the dynamic context of the semiconductor industry.

Multiple interpretations: We encountered two contrasting viewpoints. One considered that the systems would be useful if a more structured format could be included; the other rejected the systems but could not offer confident reasons. We ultimately readjusted our inquiry to analyze how knowledge was embedded in practice that was enacted in three broader systems: production systems, human collaboration, and the industrial context. This shift helped us to better explain why the engineers were unable to articulate their practice and knowledge and the limits of technology.

The principle of suspicion: There were three knowledge initiatives, managed under three different leaders. The first leader focused on organizational change and development, and was concerned with enhancing a sharing culture and establishing a governance model. The second leader was concerned with knowledge content and with employing an exchange protocol to convert tacit knowledge into explicit knowledge. The third was more worried about measuring the benefits of the system. As we came to appreciate their individual bias, we began to shift our inquiry to engineers' war stories. A critical reflection occurred when we began to assess the transfer challenge by linking together knowledge, practice, and context.

Table 1. Three Problems of Embeddedness: Knowledge, Situated Practice, and the Difficulties of Knowledge Transfer

The Complexity of Knowing	Collaboration in Knowing	The Context of Knowing
Knowledge is embedded in the complexity of maintenance practice involving the machine-to-machine interfaces and microchip fabrication process.	Knowledge is embedded in the reciprocal collaboration among technicians working around different machines in different fabrication stations and other specialists.	Knowledge is embedded in the dynamic context of the semiconductor industry. The high velocity of innovation often renders discontinuous technological knowledge.
Situated practice: In repairing machines, technicians have to relate the problem symptoms to the technical idiosyncrasy of each machine, the interface of different machines, and the integration between machines and complex fabrication processes.	*Situated practice*: In repairing machines, engineers have to collaborate closely with other engineers who oversee machines in the downstream and upstream of the fabrication process. They have to trace problems by coordinating with other machine engineers, process engineers (client sites), and suppliers (e.g., of wafer materials).	*Situated practice*: In repairing machines, technicians have to deal with customers' fast-changing demands to keep up with intensive competition. They also have to cope with the discontinuous innovation in processes, products, and machines.
The whole system is just too complex to allow technicians to record (or externalize) their knowledge about machine maintenance. What they can describe at most are the problem symptoms and snapshots of the final solution. For most engineers, such knowledge (missing all of the description of the trouble-shooting process) stored in Discover is less useful for onsite maintenance.	Working within such reciprocal interdependent relationship, engineers perform repair tasks through experimentation and experience by collaborating with other people and learning from their multidisciplinary inputs. Hence, technicians rely more on their *sense* (discovery logic) rather than on heuristics to perform trouble-shooting. The knowledge recorded in Discover is perceived as static and textbook-like, which cannot help engineers to obtain their "combat" skills.	Since each machine has a short life cycle, the knowledge accumulated in one machine is often not transferable to the next-generation model. The knowledge captured in Discover becomes obsolete quickly. Engineers are thus less motivated to provide or retrieve such knowledge from the information system.
Insight: *the repair knowledge is incomprehensible.* The maintenance of fabrication machines involves a technical system characterized by interactive complexity. Thus, it is incomprehensible to engineers (as both the knowledge producers and consumers).	Insight: *the repair knowledge is unarticulated*. Engineers alone cannot accomplish machine recovery. The maintenance of fabrication machines involves the reciprocal coordination of different social actors. Engineers have difficulties in articulating the knowledge embedded in such an intricate social system.	Insight: *the repair knowledge is discontinuous and difficult to accumulate.* The engineers' dilemma is to cope with the radical innovation of new technology in the semiconductor sector. They constantly have to renew (not accumulate) their knowledge about disruptive products, processes, and machines.

Research Findings: Knowledge Transfer and Situated Practice

Case Background

Incorporated in 1989, ChipFab Taiwan (hereafter ChipFab) is a regional office of a top U.S. manufacturer and service provider of semiconductor fabrication equipment (note: the names of the company and the systems used are disguised as requested). In this competitive industry, failure to provide timely services to clients can cause losses of millions of dollars in microchip fabrication. Hence, although knowledge sharing is vital for ChipFab, experience gained by one engineer often cannot be transferred effectively to others. This is why ChipFab decided to commit itself to a knowledge transfer initiative. The core idea of this initiative was to build a centralized database, called Discover, so that the engineers' maintenance tips could be captured and transferred efficiently to others.

The system went through two major developmental stages. First, from July 2000 to January 2001, ChipFab introduced Lotus Notes as the technological platform. ChipFab engineers traditionally had a sharing culture. They always looked for better methods and improved technology to help them disseminate maintenance knowledge in order to cope with stressful repair tasks. The Discover idea was readily accepted. The governance model of Discover resembled the academic journal review procedures. Typically, an engineer would write down his maintenance tips (e.g., on new problems in installing a machine). For each tip, the engineer followed the format of (1) abstract, (2) introduction, (3) results and discussion (lessons learned), (4) conclusion and further references. The tips were then submitted to a central clearinghouse managed by a committee consisting of 18 "knowledge champions" for content review (i.e., senior engineers). An associate editor would be appointed to review the relevance of the content, and two independent reviewers would be asked to judge its worthiness. Each tip, once approved, would be acknowledged as a "known method" and stored in the Discover database. For each known method, the engineers would receive acknowledgement at annual corporate meetings and a cash bonus. In other areas, ChipFab set up a steering committee consisting of four senior executives in order to secure top management support. A change agent was also appointed voluntarily in each department to promote the submission and retrieval of Discover.

The second stage (early 2001to mid-2002) focused on knowledge content. ChipFab enhanced the knowledge exchange protocol (focusing on the results of tips) to help engineers reflect their practice. Moreover, weekly sharing meetings were held so as to identify areas of improvement and make Discover more relevant to the needs of engineers. The Quick Notes system was added to provide the engineers with a personal Discover Webpage. By the end of 2001, ChipFab reported an encouraging result: (1) submissions to Discover had increased from 18 articles to 72 articles per month; (2) the frequency of knowledge searches in Discover had increased from 117 (at the beginning) to 1,176 per month; (3) machine average installation time had been reduced from 90 days to 30 days, (4) the time to search a knowledge content in Discover had been reduced from 15 minutes to 3.5 minutes.

A challenge soon arose from the onsite engineers. Unlike those engineers who deal mainly with machine installations, the onsite engineers had to repair machines on the clients' sites. One onsite engineers volunteered the typical sentiment:

> My time is 100% exploited. I don't have the luxury to sit down and write down my known methods. Even if I could, the known method would soon become outdated. The historical Discover archives have no relevance to my present problems. I'm an engineer, not a historian. All I have to do is just solve problems immediately.

In light of the critical assessments, at the end of 2002, ChipFab planned to add expert systems in Discover in order to support machines diagnosis. Other ideas included enriching the content of Discover and providing more training sessions so that the engineers could better "decode" (understand) these known methods.

The Problem of Embeddedness

In this section, we will describe engineers' repair war stories and present our findings under three headings: the complexity of knowing, collaboration in knowing, and the context of knowing. We look into the problems of embeddedness to highlight why Discover cannot successfully transfer engineers' repair tips. In other words, the three problems increase the difficulties of knowledge transfer enabled by information systems. We interpret the characteristics below and summarize them in Table 1.

The complexity of knowing: Why do engineers consider Discover to be of little use? The question has to be examined first from the perspective of the relationship between individual machines and the fabrication process. Unlike linear or module production systems such as automobile manufacturing, microchip fabrication consists of complex production procedures, which are tightly coupled. An engineer has to deal with not only a problematic machine but also the ways in which it interacts with a wider fabrication system. Hence, it is often impossible for them to describe the complex maintenance process in terms of Discover.

Microchips are made by interconnecting transistors to form complex electronic systems on a sliver of silicon, which is produced by an interactive series of five generic steps: (1) diffusion, (2) photo, (3) etching, (4) ion implanting, and (5) thin film. In this fabrication system, one problem in a single machine could be caused by interacting problems in other machines from the previous steps. One engineer, who repairs CVD (Chemical Vapor Disposition) machines (used in the fifth step), noted,

> If it is concerned with the problems of a single machine, I can solve it within three days. But problems are often created in previous fabrication processes. Many times, I have to trace back to more than five or six fabrication procedures.

However, most repair tasks are too complex to be resolved by just tracing problems through the fabrication processes. The engineers constantly have to undertake troubleshooting within and between machines (in different fabrication steps). One engineer maintaining ion-implanting machines described an illustrative experience. In one case, he had to support Client T to test run a mass production of a 12-inch wafer. During the ion-showing (fourth) step, the machine produced abnormal particles on the wafer (if there were more than 200 particles on a wafer, the wafer would be wasted). The engineer first used a chemical compound to clean the machine chamber. This did not work; so the engineer tried cleaning gas (i.e., NF_3: Nitrogen Trifluoride) to purge the machine chamber. The test result was normal but the machine still produced particles as fabrication proceeded.

The engineer began a mechanical check to see if the problem was caused by worn components, which was unfruitful. He then turned to high-temperature checking, which involved heating the machine to between 350 and 450^{o}C and purging gases in it. This was to check whether the particles were caused by gas under abnormal temperature. Again, the problem was not solved. Accidentally, the engineer found a worn component inside the chamber (a heat-producing susceptor). He was excited, thinking that this was the root cause, and changed the component (at a cost of about $200). But the problem still persisted. With frustration, the engineer analyzed the chemical compound of the particles, found an aluminum reaction, and surmised that it must be a problem caused by the susceptor. He replaced the susceptor again, but there was no improvement. By this time, he had spent the whole day working on the machine.

In the next two months, the engineer began to trace the fabrication process. One possibility was the thin film step (growing metal connectors in step 5). He worked with another engineer to perform a set of tests (similar to the previous steps) on the CVD machine, and examined the connections between these two machines. Without any success, he called other engineers to check on the IMD machine (Inter-Metal Dielectric, for step 5), which grows a thin film of metallic connectors on the wafer. Now there were seven engineers working on the problem. They subsequently set up a conference meeting of 10 people, including process engineers (from the client site) and other machine engineers, to follow through the fabrication process. They went through seven major checking steps and 31 minor inspection steps. Finally, they found that the problem was caused by the IMD machine.

The IMD machine was a new model, with many innovative design features and new components. When it was used to grow metallic connectors, it produced invisible particles. As the spoiled wafer was processed to the next step and interacted with the CVD at a high temperature, the particles were thus “enhanced”. The engineer spent two hours explaining the full version of this war story. He concluded:

> This is still not the most complex repairing task. In other cases, I have to trace to more “fab” steps and deal with more complex problem such as wafer materials, machine components, and convoluted production processes. I still have a bag of these problems unsolved... I am swimming in a sea of complexity. How can I describe all these interconnected problems in Discover; I mean: how can a fish describe water?

The engineers’ situated practice involved knowledge about the complex interaction of machine and machine-to-process. Mostly, with time constraints, engineers could only describe the final solution in the Discover. These known methods were considered by many engineers to be less useful, because such knowledge misses all of the contextual cues and complexity of trouble-shooting.

The collaboration in knowing: The previous example shows that engineers need to interact with machines to sense the problems in dynamic situations. They also have to work closely with other engineers reciprocally in order to trace the root problem. One engineer noted:

> The fabrication of microchips involves multidisciplinary knowledge. I cannot possibly know everything about semiconductors, such as the knowledge of electronics, physics, chemistry, mechanics, and material sciences, to name just a few.

In a reciprocal matter, the machine engineers had to work with other process engineers to identify interface problems in particular steps of fabrication. Additionally, they had to trace problems by working with suppliers (e.g., on material quality problems). In such interdependent relationships, the engineers found it difficult to establish repair heuristics. As one engineer explained,

> Every problem is unique because its situation is dependent on so many interactive variables caused by the clients, the suppliers, the machine's individual characteristics, and the fabrication process. To solve such problem, you don't count on your experience; you just have to follow your senses and collaborate with your colleagues.

The *senses* described by the engineers indicated the discovery logic used to cope with the reciprocal, interdependent mode of repairing tasks. Although Discover employed a structured format to help engineers codify the repair experience, the engineers were often exhausted by the end of a day's troubleshooting and had difficulties articulating what they "knew" in the reciprocal process. One engineer described his "silence of knowing":

> Writing a Discover only gives you a snapshot of the problem. In a typical assignment, I am engrossed by all sorts of machine parameters. I have to talk to a lot of people working around the machines in order to find out the possible culprits [root problems]. It is an ER [Emergency Room] situation; and we are like medical doctors [in relation to the machine]. By the time the job is done, I know that I know everything but I can write nothing about it.

The context of knowing: The intensive competition and disruptive innovation in the semiconductor industry also led to the challenges of knowledge management in ChipFab. The industry generally follows Moore's law (i.e., the number of transistors on an area of silicon doubles every 18 months, and consequently the cost per function of integrated circuits falls by half in about the same time). One senior engineer explained that ChipFab was facing two technological trends: bigger wafers (e.g., from 8-inch to 12-inch wafer fabrication—that means more microchips can be produced in a single wafer), and smaller circuit width (e.g., electronic components in these microchips initially measured 0.35 microns across, but now are moving to 0.13 microns—that means one microchip can contain 10 million or more transistors, with a size 500 times smaller than a strand of human hair). This results in more new machines with more powerful fabrication functions. But it causes great problems for the machine engineers, as one of them explained:

> The innovation is changing so fast that the new model of a machine is often incompatible with the previous machines. That is not the worst thing: the worst thing is that we have to relearn everything about the machine. We are often unable to accumulate what we learn by maintaining previous models of the machine.

Not only could these engineers not accumulate repair tips, they also had to deal with their clients' uncertainties. In a competitive industry, clients have to respond quickly to the market. The pressure is also imposed on the machine engineers. Often, the engineers have to deal with unexpected requests from the clients. As one engineer noted,

> We don't have to seek problems out; problems will seek us out. [For example,] our machine is designed to handle one wafer at a time [then engineers have to clean the chamber]; but my client asks me to try out a three-clean [i.e., perform the chamber cleaning only after three wafers have been processed]. Just when I have come to grips with the three-clean, they ask me to try out a five-clean. Gaining knowledge to deal with this single request has already exhausted me.

Rapid technological innovations and changing customer expectations make the engineers' knowledge less repeatable and more changeable. Therefore it is difficult to accumulate. Codifying such fluid knowledge in Discover thus becomes less meaningful for the engineers. As one engineer noted with some annoyance,

> Discover is a waste of my time. I am operating the most advanced machine. Before I can recall what I learn, I have to move on and learn new stuff. How can those so-called Discover *knowledge champions* judge the value of my submission? Their knowledge is perhaps three generations out of date compared to mine [i.e., in terms of models of the machine].

Discussion

From previous three findings, we set out to understand the challenges of knowledge transfer enabled by information systems. One interesting issue is that although Discover is similar to knowledge sharing systems like Eureka in Xerox (Brown and Duguid 1991, 2000), ChipFab seems to have faced a different set of challenges. We contrasted the problems of Discover with those of Eureka according to our three findings. The purpose of this comparison is to show the possible variations between two distinct practices. With this comparative explanation, we want to identify the potential theoretical contributions of this research to the current literature on situated practice and information systems.

Why Eureka Succeeds, but Discovery Fails?

Eureka, a widely cited case, is a database instituted by Xerox to manage knowledge dissemination among 25,000 repair technicians (for a more complete account of Xerox technicians' practices, see Brown and Duguid 2000; Ellis 2001; Orr 1996). Xerox technicians can submit repair tips to a centralized review process. Experienced technicians assess the tips, accepting some, rejecting others, and eliminating duplicates. If the tips survive the process, the knowledge is stored in Eureka and shared worldwide. The Eureka database has more than 30,000 records and has resulted in envious success, saving Xerox over $100 million (up to the year 2000). Like the photocopier technicians of Xerox, these engineers have an immediate need to share their repair tips in order to deal with dysfunctional machines.

ChipFab's managers have also invested in a Eureka-like system for knowledge transfer—Discover. However, with a similar environment, governance mechanism, and system features as those of Xerox, the knowledge transfer initiative in the microchip fabrication case has encountered many more challenges. With this puzzle in mind, we aim to examine the problem of knowledge transfer from the perspective of situated practice. Figure 1 summarizes the differences between Discover and Eureka according to the three dimensions explained in the previous section. The purpose of the comparison is to understand how practice may constrain the use of an information system in facilitating knowledge transfer.

Linear vs. interactive complexity: We first compare the complexity of knowing between the two companies. The repair task facing Xerox's technicians can be characterized as one of linear complexity: the repair of photocopier machines consists of an expected maintenance sequence that is fairly visible even if it is unplanned. The repair task can be undertaken in a step-by-step fashion. However, ChipFab engineers practice in a technical system featured by "interactive complexity" (Perrow 1999): machine repair consists of an unfamiliar and unexpected maintenance sequence, which is not immediately comprehensible. The repairing tasks often involve interactive feedbacks between the machine and the production process. ChipFab engineers thus have difficulty in comprehending the complexity situated in practice and by expressing it in written form as "known methods."

Pool vs. reciprocal mode of collaboration: The second difference is the collaboration of knowing. Kumar and van Dissel (1996, p. 287) explain three modes of collaboration: pooled, sequential, and reciprocal. In the pooled mode of collaboration, participants accomplish work independently. In sequential mode, they have to pass on tasks following particular workflows. In the reciprocal mode, participants have to work closely with mutual adjustments. For Xerox's technicians, the maintenance of photocopier machines involves only minimal mutual collaboration, because any participating technician can withdraw from the task. As long as there is no significant corresponding withdrawal of resources, the others can continue to work uninterrupted. In contrast, Lam's (1997) study of Japanese engineers' electronics design work reveals more of a sequential mode of collaboration, albeit an overlapping model.

However, ChipFab's engineers provide each other with assistance in no particular predefined sequence. Problems in one machine can affect downstream as well as upstream fabrication. In fact, the concept of upstream and downstream is no longer meaningful, as the engineers feed work back and forth to each other. As problems are often enacted within dynamic situations, when engineers finally complete their maintenance jobs, they have difficulties articulating the reciprocal collaboration process. Even when the memory can be recorded, it is static and less useful for ChipFab's engineers' dynamic collaborative problem-solving.

Stable vs. dynamics context: The third difference is the context of knowing. The technology of photocopier machines is relatively stable in comparison to other high-tech (e.g., semiconductor) products. As the innovation follows a series of smooth S curves (Christensen 1997; see Figure 1, third row), the photocopier technicians can thus benefit from the accumulation of knowledge content. However, ChipFab's engineers work within a dynamic industrial context that generally follows Moore's law (Hutcheson and Hutcheson 1997). The result is that more new products, fabrication processes, and machines are created in a very short lifecycle and with little reference to the past knowledge. Christensen (1997) explains that such disruptive innovations bring about discontinuous knowledge. The engineers thus have difficulty in accumulating knowledge in machine maintenance.

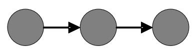
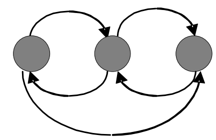
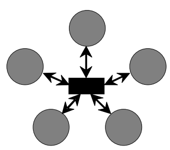
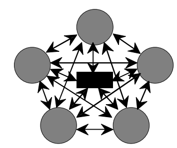
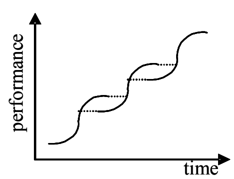
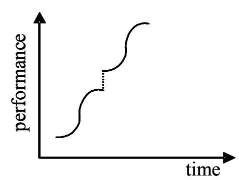
	Situated practice in Xerox		Situated practice in ChipFab	
The complexity of practice		Linear complexity: The repair of photocopier machines consists of an expected maintenance sequence that is relatively visible even if it is unplanned. ◄ …...the circles symbolize the technicians/engineers ……… ►		Interactive complexity: The repair of microchip fabrication machines consists of an unfamiliar maintenance sequence which is not immediately comprehensible. The repair tasks are performed in feedback loops (between machine -to-machine and machine -to-process).
Collaboration in practice		Pool mode of collaboration: The maintenance of photocopier machines involves the least amount of interdependence, because any technician can withdraw. As long as there is no significant corresponding withdrawal of resources, the others can continue to work uninterrupted. ◄ …...the black box in the center symbolizes the machine …►		Reciprocal mode of collaboration: The maintenance of fabrication machines requires interdependent coordination. Technicians provide each other with assistance in no particular predefined sequence. Problems in one machine can affect the downstream as well as the upstream fabrication processes.
The context of practice		Stable context: The technology of the photocopier machine is relatively stable in comparison to that of other high-tech products. As the innovation follows a continuous S curve, the technicians can benefit from the accumulation of knowledge content (in machine maintenance).		Dynamic context: Innovation in the semiconductor industry generally follows Moore's law. New products, fabrication processes, and machines are created with a very short lifecycle. These disruptive innovations bring about discontinuous knowledge.

Figure 1. Situated Practice—Xerox vs. ChipFab

The three dimensions help us understand better why Xerox's technicians can benefit from using the repair tip database (Eureka) to share their war stories, whereas ChipFab's engineers cannot benefit from Discover because they have to fight with the complexity of the integrated fabrication process, collaborate closely with colleagues, and cope with customers' insatiable demands. We can also appreciate why ChipFab's engineers cannot share their war stories and feel powerless in using the information system despite their enthusiasm.

Theoretical and Managerial Implications

This study adds to the cumulative literature on tacit knowledge and situated practice. In contrast to other traditional types of knowledge worker, we find a distinct type of engineer who maintains high-tech equipment in dynamic contexts. Their knowledge is like a gear wheel embedded in the complex system. Before understanding the embeddedness of such tacit knowledge, we should not use information technology arbitrarily. In this paper, we explain three analytical points that characterize their tacit knowledge. On this basis, we not only join the strand of practice-lens research and understand the nature of tacit knowledge, but gain some implications for knowledge transfer (cf. Barley 1996; Lam 1997; Lave and Wenger 1991; Orlikowski 2002; Tyre and von Hippel 1997). Moreover, this study complements the present literature by placing more emphasis on the practice of knowledge worker characterized with interactive complexity, reciprocal collaboration, and dynamic context, rather than on technological features (Storey and Barnett 2000), inhibiting barriers (Rivikin 2001; Szulanski 1996), and organizational impediments (Hayes and Walsham 2001). In sum, the more we understand the nature of tacit knowledge, the more confident we become in deploying knowledge sharing systems.

Furthermore, this study adds to the practice analysis of information systems implementation (e.g., Nidumolu et al. 2001; Schultze and Boland 2000). Based on the comparison between Eureka and Discover from the previous section, it is essential to consider three parts to transfer knowledge effectively. First, managers have to reflect the characteristics of tacit knowledge in ways similar to the Eureka or the Discover style and avoid putting static information that is detached from engineers' working contexts. Second, in facing situations similar to ChipFab, managers may consider documenting the discovery logic of each troubleshooting practice, rather than capturing snapshots of their war stories. For example, external experts could be invited to codify Discover with rich context using multimedia technology and enhance engineers' interpretative capability of Discover. Third, managers also have to decide how to use information systems in proper ways. They not only have to store knowledge content through information systems but have to facilitate actual practice in a dynamic way. For example, Discover may add features of online trouble-shooting. Engineers distributed in different functional and geographical areas may help each other through onsite technical support.

Based on the findings of this research, we suggest three directions for future research. First, we need to examine the relationship between knowledge producers and consumers. In the Eureka case, knowledge consumers can be the producers, whereas in the Discover case, knowledge consumers cannot benefit from their own production (due to their incomprehension of interactive complexity). One possible direction is to analyze how information systems can support the transfer of knowledge embedded in practice situated in interactive complexity. Second, we can use informal networks to describe the relationship of technicians. If we can know clearly how knowledge flow is embedded in the community, it will be easier for us to consider the role of information systems in facilitating knowledge transfer within these informal activities. Third, we may reconsider the role of information systems to transfer the short lifecycle of knowledge embedded in practice situated in a dynamic industrial context (e.g., through the real-time exchange of hands-on experience).

Conclusion

Previously, Barley (1996) urged researchers to examine the nature of knowledge in modern jobs so as to produce relevant interpretations of organizational phenomena. In order to embark on this challenge, we examine the work of microchip machine engineers and the knowledge embedded in their situated practices. The study suggests that the difficulty of knowledge transfer must be understood in relation to the embedded nature of knowledge. With such an enhanced understanding, in the future we may be able to know how to cope with such knowledge and employ information technology for knowledge transfer with greater confidence.

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